TACTICAL BATTLEFIELD VISUALIZATION OF FORECAST WEATHER AND EFFECTS

Donald W. Hoock Jr.
David H. Tofsted
U.S. Army Research Laboratory
Information Science and Technology Directorate
Battlefield Environment Division
White Sands Missile Range, NM 88002-5501

John C. Giever
Physical Science Laboratory
New Mexico State University
Las Cruces, NM 88003

ABSTRACT

Someday, battlefield commanders and staff will routinely immerse themselves in virtual battlefields. There they will tap into intuitive, multi-dimensional, seamlessly-distributed digital databases. They will be aided by "smart software" to help them assess the threat, plan the mission and gain situational awareness. This will exploit knowledge of the current state of the battlespace, including forecast effects and impacts on weapons, tactics and operations of dynamic weather, terrain, illumination and battle-induced environments. The reality of the present, however, is that we are only in the first phase of these advances. An ability to collect, process and use digital information on the battlefield is fairly recent. We are just beginning to see the benefits of automating and speeding up even such traditional tasks as production of text messages, 2D data overlays and tactical maps in the field. This paper shows how existing technology might be easily adapted to further advance the visualization of meteorological information, effects and impacts. We consider Vis5D, the 3-D data visualization software from the University of Wisconsin. This publicly-licensed software has desirable properties of "open" source codes, cross-platform execution and flexibility. We demonstrate how the meteorological forecast outputs of the Battlescale Forecast Model can be interfaced to the Vis5D viewer and extended to include other data and derived effects parameters. We contrast the performance of the product on different computers to highlight the need for future tactical computer hardware standards to include graphics hardware that can run under "open" graphics languages. And we extend the data-visualization concept to 3-D visual immersion and data-focus for mission planning purposes.

INTRODUCTION

Technology demonstrations indicate that the Tactical Operations Centers (TOC's) of the future will be highly automated and interoperable, sharing many digital information products. Battlefield commanders and staff will be able to routinely immerse themselves in "virtual battlefields". There they will tap into intuitive, multidimensional, seamlessly-distributed digital information databases. They will be aided by "smart software" to help them easily extract and synthesize critical information to assess the threat, plan the mission and gain situation awareness.

Realization of this vision may be several years away, however. Currently text messages, paper maps and overlays are still evolving into digital maps and 2-D graphic screen overlays, with analysis information shared via data tables and images downloaded by direct file transfers. Data exchange interfaces may soon evolve to include distributed "push-pull" database access and "client-server" architectures, perhaps within some form of a "web-page and browser" environment.

In the spirit of this information evolution, we describe in this paper a current effort to adapt a 3-dimensional weather and effects data-visualization tool to support weather forecast analysis and display from the Battlescale Forecast Model (BFM). BFM is part of the tactical Integrated Meteorological System (IMETS). The existing 3-D weather data display software being adapted is Vis5D (Hibbard and Paul, 1996).

Vis5D is a publicly-licensed software package from the University of Wisconsin for visualizing data produced from numerical weather models. It has the desirable properties of being widely used and portable between many different computer systems. In the following sections we describe Vis5D and its application to BFM outputs. The data visualized can, however, also include derived weather effects and weather impacts.

INTEGRATED METEOROLOGICAL SYSTEM AND BATTLESCALE FORECAST MODEL

The U. S. Army's Integrated Meteorological System (IMETS) supports the warfighter in the Tactical Operations Centers on the battlefield. Fourteen units have been fielded, and an additional eighteen are scheduled. IMETS runs on Army Common Hardware/Software (ACHS). Current Block II ACHS is a SUN Spare 20 (replacing earlier Block I HP computers). Included in IMETS is the Battlescale Forecast Model (BFM, Lee, 1994). BFM is remarkable for its ability to produce high resolution, 24 hour forecasts on this desktop battlefield system at a horizontal spacing of typically 10 km or 5 km (or even 2 km horizontal grid spacing if necessary) over regions from 500x500 km to 100x1OO km, and at 16 unevenly spaced vertical levels from the ground surface up to 7 km AGL. BFM currently uses DTED terrain elevation data. BFM is initialized using coarser-grid forecast data, for example from the Air Force Global Spectral Model (GSM) and the Navy Operational Global Atmospheric Prediction System (NOGAPS), which are global-scale models, plus observations and soundings in the battle area. The U. S. Army Research Laboratory (ARL) Battlefield Environment Division is responsible for the development and integration of software models and analysis tools into IMETS.

Figure 1 shows one example of a tactical display of BFM output on IMETS. The data here are wind speed streamlines forecast for a region of Bosnia and displayed over a 2-D map provided by a map server. Using IMETS, many other types of 2-D "overlays" and 1-D vertical profile displays of meteorological forecast data can be generated in the field, including analysis outputs from Integrated Weather Effects Decision Aids (IWEDA). These latter products show the impacts of critical values of weather parameters on military subsystems, systems, platforms and mission operations. Although future emphasis will include 3-D visualization of IWEDA outputs and dynamic weather effects at finer scales, we concentrate here on improving visualization of the weather data itself for the fielded IMETS.

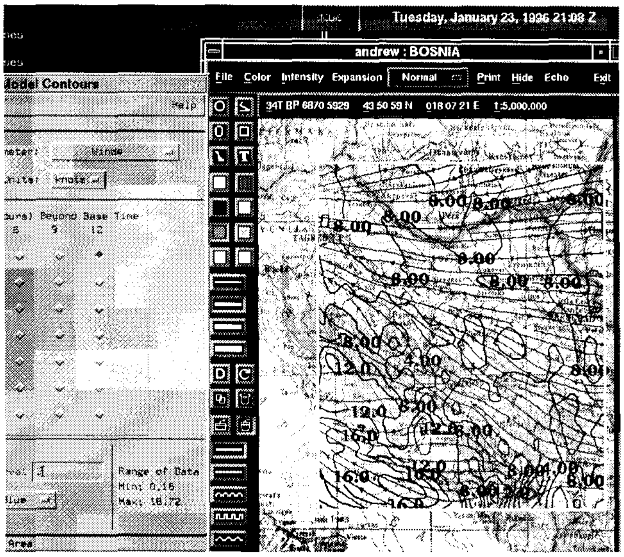

Figure 1. IMETS BFM Display

BFM is a hydrostatic forecast model that is sufficiently compact to run on the ACHS Spare 20 desktop while delivering the high spatial resolutions needed for predicting terrain-coupled effects at tactical scales. Figure 2 shows the spatial and time scales of representative meteorological features and atmospheric effects. At scales below about 5 km, prediction of the mean meteorological conditions can be supplemented by other models or by observations. These can include: diagnostic models of near surface, terrain-coupled mean winds, such as the ARL High Resolution Wind Model (HRW, Cionco and Beyers, 1995), dynamic physical simulations (such as Large Eddy Simulation) or statistical representation of dynamic fluctuations about the mean. Future efforts will include simulation and data visualization of these finer scale data and of derived effects parameters as discussed in a later section.

ARL is currently extending IMETS basic weather data visualization capability to three dimensions and time. The requirement is for a 3D software graphics package that meets the following criteria:

(1) It must not require changes to the existing BFM and IWEDA software, but must be a true "add-on" that acts only on the forecast and analysis data outputs.

(2) It must be an easily and separately maintainable software package with at most a few, well-documented code changes required to adapt any new revisions of the graphics package library back into IMETS applications. It must allow access to the graphics source code library to permit debugging should any code problems be identified in the future. It must be easily extended to accommodate any new data types generated from future improved IMETS forecast and

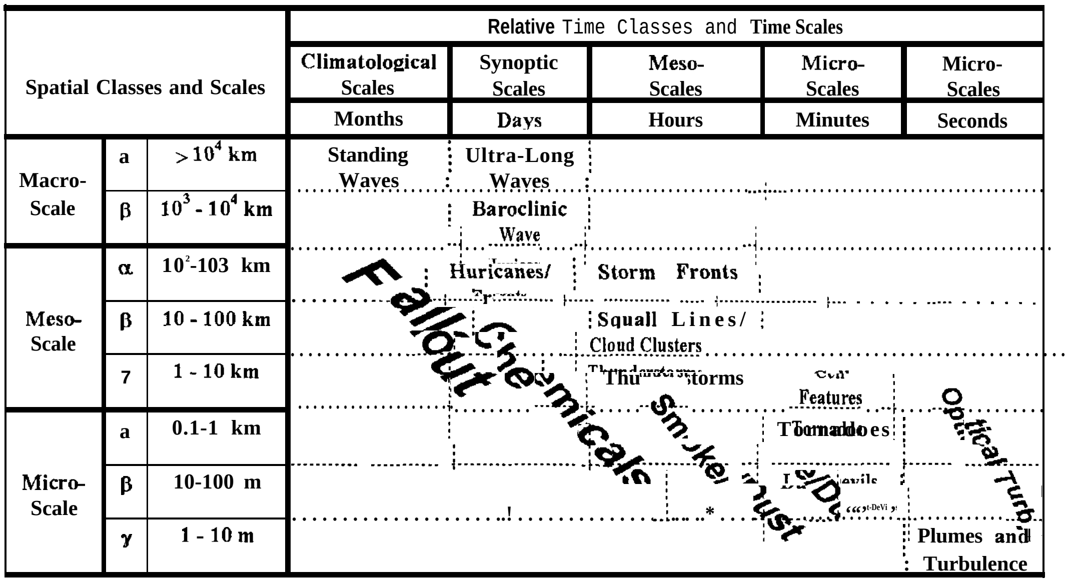

Figure 2. Spatial and Time Scale Classes

analysis capabilities. And it must be both cost effective and widely used to assure that it will be able to exploit future improvements in ACHS capabilities.

(3) It must provide at least the same capabilities of portraying stream flow, labeled contours, color-coded data bands, and vector fields as current 2-D displays. This includes the ability to easily incorporate the same map underlays currently in IMETS, as well as 3-D extensions such as data isosurfaces, volumetric color-coded data and the topographic elevation data actually used in the IMETS forecast and analysis codes.

(4) It must be a tool that is easy to learn and be interactive to allow the analyst to quickly change the data displays and 3-D viewpoint. This will permit the user to concentrate on analysis of the weather data. And it must include a capability for the user to easily record "snapshots" of the displayed images for digital transmission, for incorporation into weather briefings and for publishing on a home-page environment.

A graphics package that comes very close to meeting these requirements is the University of Wisconsin Vis5D viewer. Vis5D is publicly licensed and comes with the source code. It can run on the ACHS desktop systems and on many other computers. As we discuss below, only minimal changes (actually extensions) to the Vis5D graphics library have been required that adapt contouring algorithms to the specific terrain-coupled vertical data layer spacing used by BFM. Much of the computer code developed to allow the use of Vis5D has thus focused on writing intermediate data

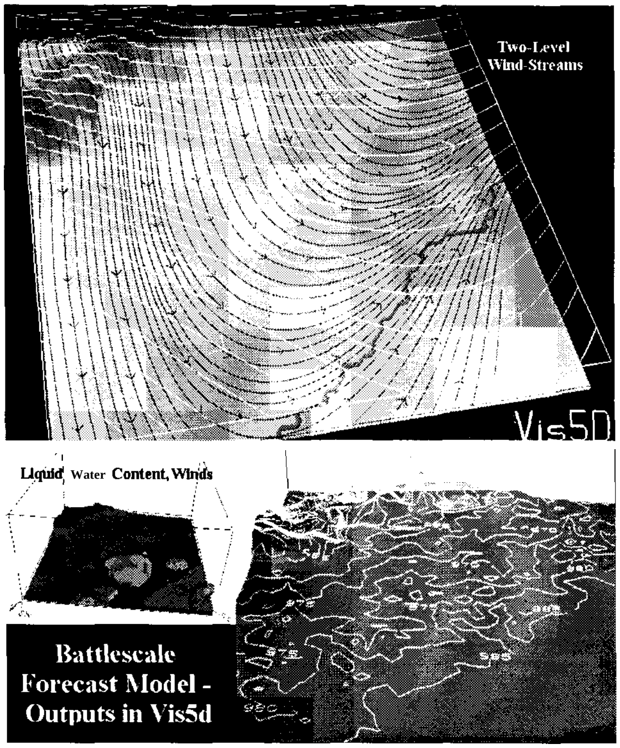

Figure 3. BFM in Vis5D Viewer

format conversion software to transform IMETS output data into standard Vis5D input data formats.

Figure 3 is a composite of examples of BFM forecast data from the Joint Warfighter Interoperability Demonstration (JWID-96) as displayed in Vis5D. It shows forecast wind streams at two levels, liquid water content contours and isosurfaces, and near-surface pressure contours. These data are displayed over the default pseudo-colored topographic elevation data of the South and North Carolina regions, with the Appalachian mountains in the northwest corner.

Figure 4 shows another example of the more sophisticated display capabilities using Vis5D to view BFM outputs. Here a color-coded volume rendering of winds over the Appalachian region shows the strong influence of the mountains on forecast wind speeds with height. The inset figures display isosurfaces of constant liquid water content forecast over the coastline and the isosurface of pressure over the mountains.

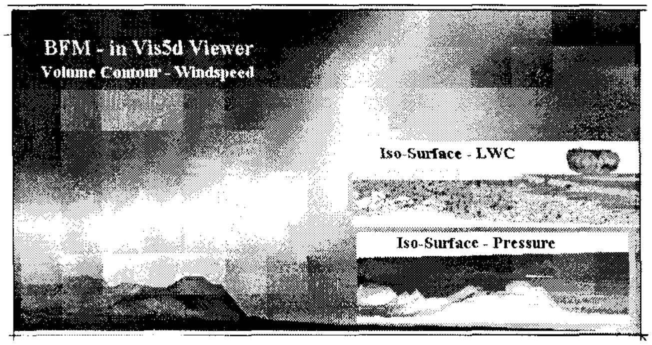

Figure 4. BFM **in Vis5D Viewer**

VIS5D HISTORY

Vis5D (Hibbard and Paul, 1996) is a software system for visualizing data made by numerical weather models and similar sources. Vis5D, version 4.2, 3-dimensional data-visualization software is publicly available from the University of Wisconsin under the terms of a GNU General Public License.

Vis5D version 1.0 was written in 1988 by Bill Hibbard and Dave Santek, of the University of Wisconsin Space Science and Engineering Center and by Marie-Francoise Voidrot-Martinez of the French Meteorology Office. Later version enhancements were written by Bill Hibbard, Brian Paul, and by Andre Battaiola of CPTEC, Sao Paulo, Brazil, plus porting to a number of different computer systems by a number of international contributors. Version 1.0 was written for the Stellar computer system. Version 2.1 in 1992 made Vis5D available for the SGI and IBM workstations. Version 3.3 in 1994 ported Vis5D to HP, DEC, Sun, and Kubota (DEC Alpha) workstations. Portability was enhanced by implementations in the OpenGL graphics standard. Version 4.1 in 1995 made OpenGL work-alike 3-D rendering software available for workstations that do not have dedicated graphics rendering hardware by using the Mesa graphics library. The Vis5D source code, executable and the Mesa graphics library can be downloaded from the World Wide Web at the URL: http:llwww.ssec.wise.edul ~billh/vis5d.html [or by ftp from iris.ssec.wise.edu (144.92 .108.63).]

Vis5D currently works with computer systems having at least 32MB of RAM and at least an 8-bit color display, including:

Silicon Graphics workstations with IRIX versions 4.x and 5.x. (Hardware graphics is used and multiple processors are supported if present);

IBM RS/6000 workstations Model 320H or higher with AIX version 3 or later. (Hardware graphics is supported through OpenGL);

HP **series 7000 or 9000** workstations with HP-UX A.09.O 1 or later (PEX optional);

Sun Spare workstations with SunOS 5.x or later. (Graphics uses main CPU with the Mesa library);

DEC Alpha workstations with OSF/1 V1.3 or later. (Kubota Denali Graphics hardware is supported with KWS V 1.3.3 or later and NPGL run-time license);

IBM PC compatibles with Linux 1.0 or later and 75 MHz Pentium CPU or faster. (The XFree86 X window system must be installed.)

USER INTERFACE

The Vis5D user interface consists of an options menu and a rotatable data viewing box. The screen menu is shown in Fig. 5. The data viewing area appears as a data box as shown in Fig. 6, which can be rotated to any viewpoint, shifted and zoomed. The box is labeled in latitude, longitude, height AGL (in our implementation) and identifies the north direction.

The upper part of the menu allows the user to: animate or step through the data in time; toggle on/off display of the terrain topographic elevations; toggle on/off a bitmapped texture (map) underlay over the terrain at the bottom of the box; toggle on/off a vector map underlay; initialize the view to various directions; switch between orthographic and perspective views; reverse window background to black or white; toggle time of day and legends; dump displays to image files; and includes options for additional variables and input of scripted display information.

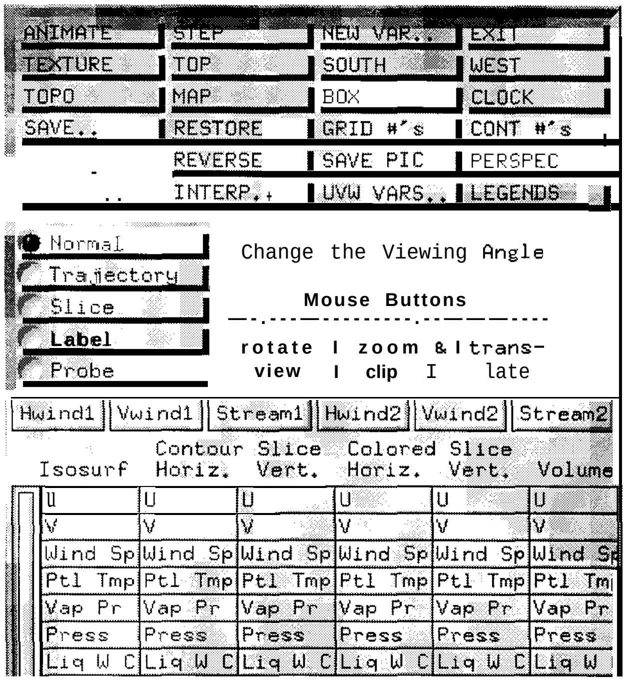

Figure 5. Vis5D Menu

The middle menu: manipulates the positions of displayed data slices in the viewing volume; adds text labels; and displays the meteorological data at any point in the 3-D volume via a pointer "probe". The bottom menu selects the data and the variables to be simultaneously displayed. Variables on menu buttons are defined in an ARL-developed input file, discussed below, while meteorological data come from a file via an ARL code that reformats them for Vis5D.

ELEVATIONAND MAPDISPLAYS

Elevation datain height above mean sea level are the same values and spacing used by BFM in the forecast calculations. The Vis5D''topo'' elevation data file is generated by a stand-alone pre-processor code ***CNVRTOPO.C*** provided by ARL to convert BFM topo array data conventions to Vis5D topo array data conventions. The BFM topo array convention stores data first by rows scanned south to north in each column, which are then each scanned west to east. The BFM longitude convention is negative west longitudes. The Vis5D topo array convention requires elevations stored first by columns, scanned west to east for each row, which are then each scanned north to south. The Vis5D longitude convention requires positive west longitudes. In addition, Vis5D elevation encoding requires the least significant bit to be assigned a zero or a one representing a land or water surface. Figure 7 shows displayed topographic elevations in Vis5D for the JWID-96 exercise, with the Appalachians of North Carolina in the northwest corner. When the "topo"

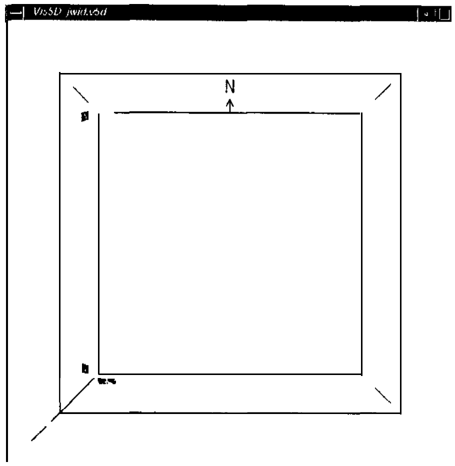

Figure 6. Vis5D Data Viewing Box

display option is turned on without "texture" turned on, then Vis5D produces a default (user-adjustable) pseudo-colored terrain with blue water, and green lowlands that shade to a yellow-red in mountain regions. Normally, we set up Vis5D to display an exaggerated vertical scale on the box (of 10 to 40 times the horizontal scale, typically). This allows the vertical detail in meteorological data levels to be more easily discerned by the user. Topographic elevations are similarly exaggerated to assure that near-surface meteorological data display properly on top of the topographic surface.

The bit-mapped underlay at the bottom of the display box is setup to accommodate any image file as a texture. The texture will drape over the elevation data when the "topo" display is turned on, or will lie flat at the bottom of the display box when the "topo" display option is turned off. One can use, for example, the map generated for the BFM output from the

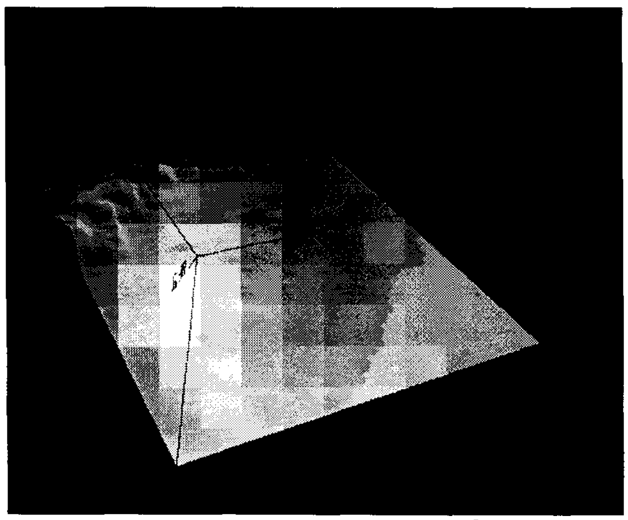
Figure 7. Vis5D Using BFM Topo Elevations

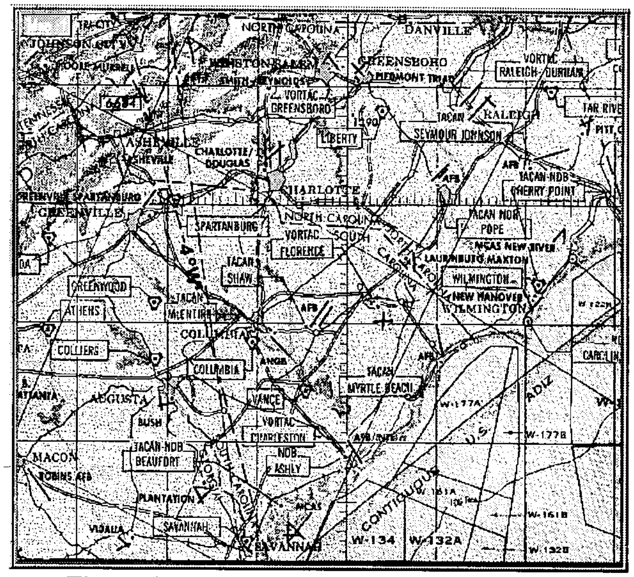

Figure 8. IMETS Generated Map Underlay

IMETS map server as shown in Fig. 8. Or the user can supply any other map, for example the U.S. Census Bureau map shown in Fig. 9, for the same region. Vis5D supports this image in SGI ".rgb" image format. We convert the image file from the more typical image formats, such as ".gif" into the SGI format in a separate pre-processing step.

Figure 10 shows an example of the combination of both "topo" elevations and the map "texture" turned on simultaneously,

CODE MODIFICATIONS REQUIRED FOR BFM

We would like to implement Vis5D without any code changes. This would facilitate very simple software maintenance by total Vis5D code replacement as new versions of Vis5D are released. Unfortunately, however, minor coding changes are necessary to accommodate the correct "terrain-following" height at which BFM forecasts are made. In BFM each of the 16 layers is specified as a "height above ground level". But at each horizontal location this means that the actual layer height relative to sea level will vary with terrain. So the data layers are not flat. The scaling convention is such that the highest (say 16th) layer <u>is</u> flat, while the lowest (1st) layer conforms almost exactly to the topography. The corrected vertical layer height $\mathbf{Z_{msl}}$ above sea level in terms of the BFM relative layer height above ground level $\mathbf{Z_{agl}}$ at a point where the terrain elevation above sea level is $\mathbf{Z_{ter}}$ is defined as:

$$\mathbf{Z}_{msl} = \mathbf{Z}_{ter} + \left(\mathbf{Z}_{agl} \big/ \mathbf{Z}_{max\,agl} \right) \bullet (\mathbf{Z}_{max\,msl} - \mathbf{Z}_{ter}) \quad (1)$$

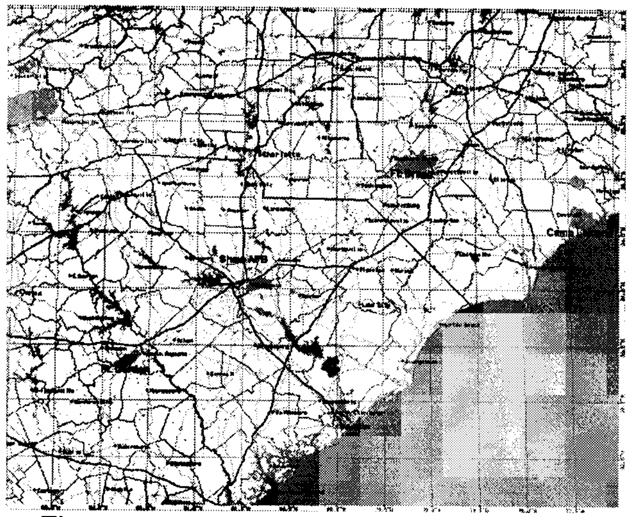

Figure 9. Arbitrary (US Census) Map Underlay

where $\mathbf{Z_{maxmsl}}$ is a fixed height of the top of the BFM computation box ($\mathbf{Z_{maxagl}}$ + max terrain height relative to sea level), and $\mathbf{Z_{maxagl}}$ is currently fixed in BFM at a value of 7000 m above ground level.

This algorithm is inserted into the vector, contouring, volumetric rendering and isosurface generation subroutines such that the meteorological data are all adjusted for the terrain elevation changes. Thus, near the surface the contours "drape" over the terrain surfaces, while at the upper height levels they become more flat. This is apparent in examples of the next sections. The coding changes are well documented and few so that maintenance for new Vis5D versions is relatively simple. Furthermore, if a user downloads Vis5D from the University of Wisconsin and uses it without the BFM layer corrections, then the BFM data are still viewable, but

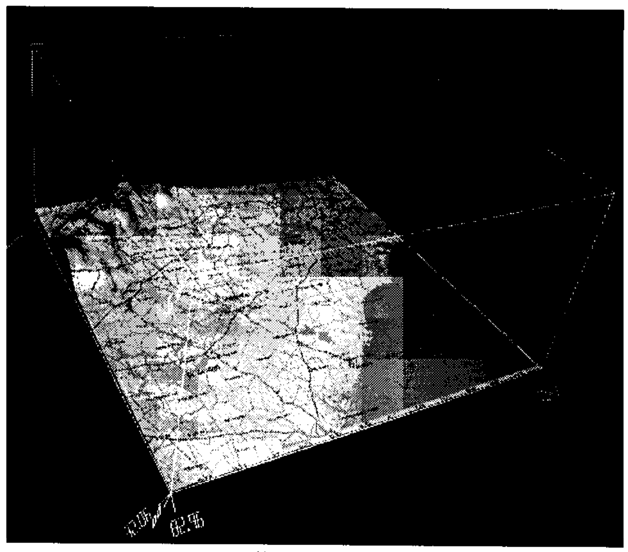

Figure 10. Both "Topo" and "Texture" On

all BFM data appear as flat layers with height relative to the bottom of the Vis5D viewing box. (Although in this case low-level data may appear "below" terrain.)

DATA INTERFACE

As BFM itself is upgraded and new meteorological variables are produced, one would like to be able to easily display these data in Vis5D. Therefore, an intermediate code to reformat BFM data into the input convention of Vis5D was produced. This separate conversion filter routine, called ***BFM_to_V5D.F,*** reads an ascii file that is easily modified using any text editor. The ascii file contains a list of all possible data labels and units (currently 37), flags the active BFM output meteorological variables (currently 13), designates units conversions, and specifies the order in which variables occur in the BFM output file. The conversion filter then reformats the data into a form that can be loaded directly into Vis5D, along with the "button labels" (up to 30) seen in the bottom portion of the Vis5D menu. This filter thus allows one to easily take into account BFM code upgrades and changes without a need to modify either BFM or Vis5D for viewing the new data.

(In spring 1997, ARL will change over from reading BFM output files directly and will instead query a database which is populated with BFM outputs. Thus, the conversion filter routine will be modified to accommodate any meteorological data in the database itself. After this change-over is complete it should not matter what the source of the data are in the database, whether from a forecast model or from a gridded set of observations. Changes in new versions of Vis5D rendering routines will still be required, however, to take the corresponding BFM vertical layer height scaling convention into account.)

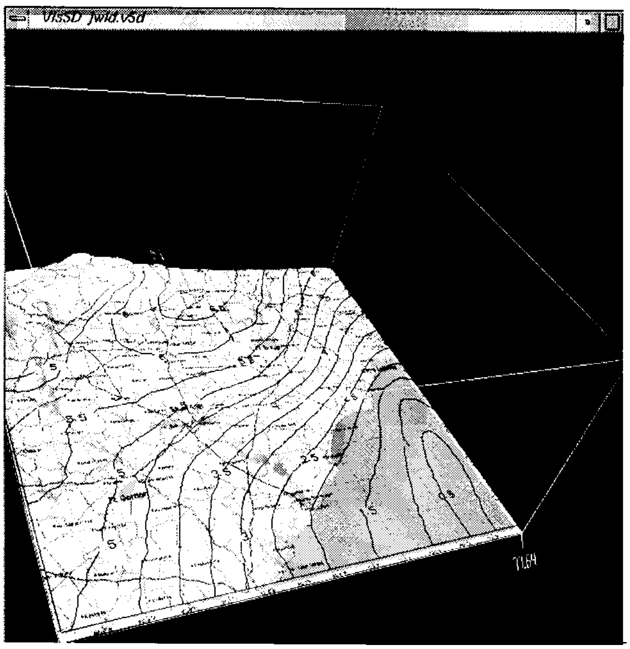

Figure 11. Example of Wind Speed Contours

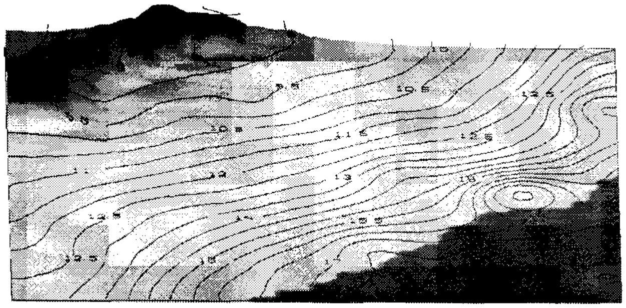

Figure 12. Water Vapor Pressure Contours

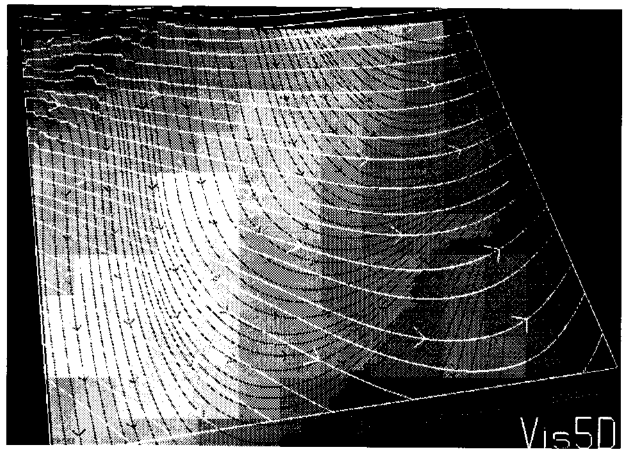

Figure 13. Wind Streams at Two Levels

EXAMPLES

Figure 11 shows a wind speed contour at a low height over the map and topo displays. In this example, Vis5D <u>with no code modifications</u> has been used so the data contours pass "beneath the mountain". Figure 12, however, shows near-surface water vapor pressure contours. Here the Vis5D code has been modified to include the BFM height AGL corrections. The data thus "drape" over the mountains Figure 13 displays wind streams at two heights. Note that the wind fields show significant turning between the 300 and 3000 m heights. Vis5D allows data at multiple levels to displayed (from default buttons or by "cloning" with the "new variable" button.) Thus, the analyst can identify significant features and capture an image of them for use in weather briefings and homepages. Figure 14 shows that Vis5D can also display the wind as vectors, showing both speed and direction for each layer.

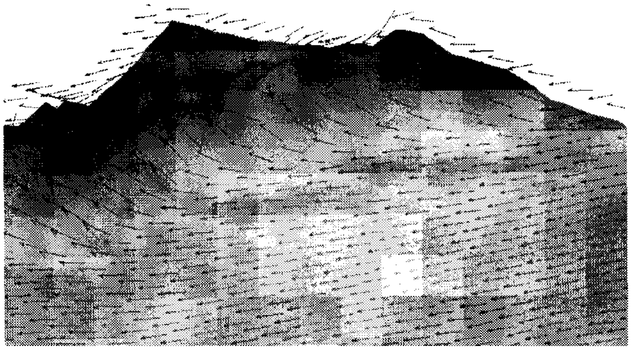

Figure 14. Near-Surface Wind Vectors

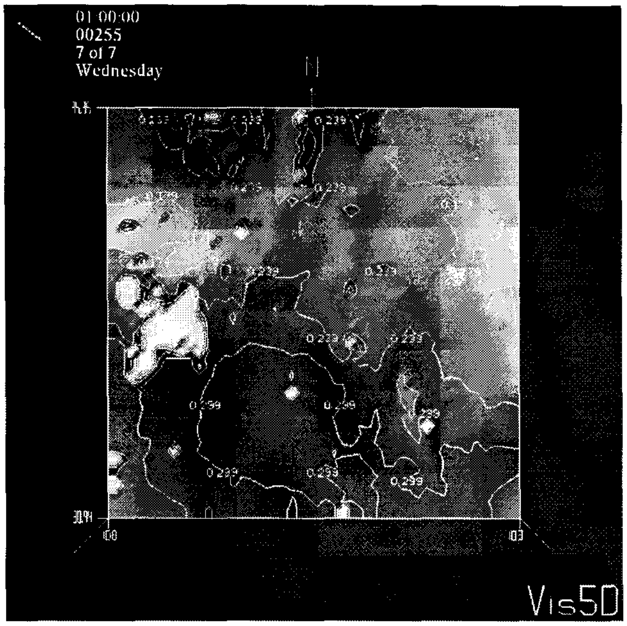

Figure 15. Accumulated Precipitation

The examples thus far are from the IMETS forecasts at JWID-96. Figure 15 is an accumulated rainfall forecast for the Ft. Hood area in preparation for Task Force XXI exercises. The data are displayed in Vis5D as both labeled contours and as colorized contour areas. This combination thus displays both quantitative reference contours and also the detail in the gradual (256 color-palette) shading.

Figure 16 shows that line and area contours can also be displayed as a slice in the vertical. Colored wind speed contours above the mountain are shown along with wind streams at two horizontal levels.

FUTURE DERIVED EFFECTS DISPLAY

A new Army Science and Technology Objective (STO), Weather Effects and Battlescale Forecasts for Combat Simulation and Training, has the objective of making the IMETS capabilities an asset for use in mission planning, training and simulations. Currently IMETS has been "isolated" to the tactical operations centers on the battlefield and to ACHS hardware and software. Under this STO we will not only make the IMETS assets available to the outside simulation communities, but will also use models and simulations to make new derived environmental effects parameters and weather impacts available to IMETS.

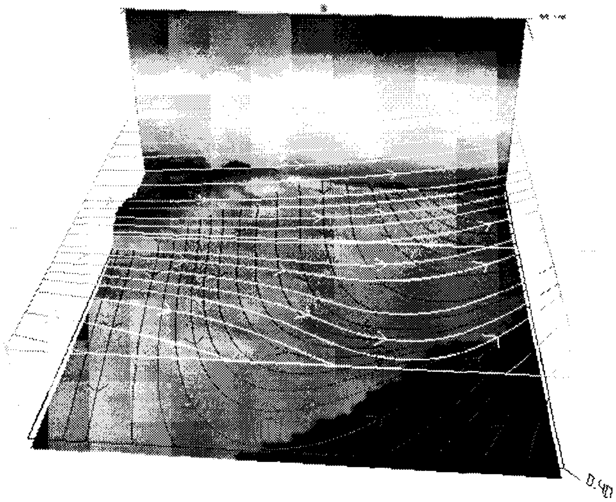

Figure 16. Wind Speed Area Contour in Vertical

Examples of simple, derived parameters are shown in Vis5D displays in Figures 17 through 19. Air temperature T ("C) can be derived from the BFM potential temperature θ ("K) and pressure P (rob) from:

$$T = \theta \cdot \left(\frac{P}{1000}\right)^{2/7} - 273.16 \tag{2}$$

and the optical refractivity N, required to compute refractive bending, can be derived for a wavelength λ (μm), the pressure P (rob), temperature T ("C) and water vapor pressure f (rob) from:

$$N = (n-1)\cdot 10^{6} = A(\lambda)\cdot G(P,T) - B(\lambda)\cdot H(f,T) \tag{3}$$

where n is the index of refraction and:

$$A(\lambda) = 0.378125 + \frac{0.0021414}{\lambda^2} + \frac{0.00001793}{\lambda^4} \tag{4}$$

$$B(\lambda) = 0.0624 - \frac{0.00068}{\lambda^2} \tag{5}$$

$$G(P,T) = P \cdot \frac{\left[1 + (1.049 - 0.0157 \cdot T)\cdot P \cdot 10^{-6}\right]}{1 + 0.00366 \cdot T} \tag{6}$$

$$H(f,T) = \frac{f}{1+\ 0.003661.\ T} \quad (7)$$

Figure 17 displays forecast refractivity as contours at two levels above ground as derived from a BFM forecast. The small compact region of contours at an upper level in Fig. 17 is shown in Fig. 18 to be due to a forecast region of high liquid water content (clouds). Figure 18 shows a Vis5D isosurface of constant liquid water content, the wind stream at a high altitude, and a semi-transparent contour of refractivity at a near-surface level that allows the underlying map to show through. Vis5D allows many surfaces (area contours and isosurfaces) to be rendered with a user-adjusted semi-transparency. This is especially useful if several variables are being displayed simultaneously, with one set of features that would otherwise be hidden by another.

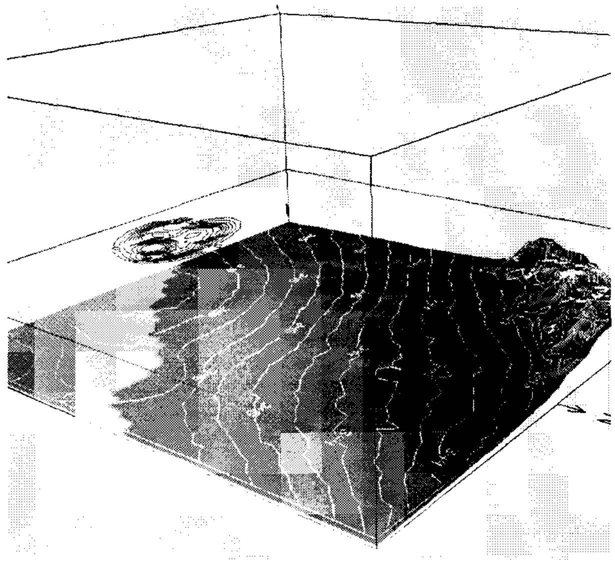

Figure 17. Refractivity at Two Levels

Another derived parameter for atmospheric effects is sound speed V (in m/s):

$$v = 331.45.\sqrt{1+\left(T/273.16\right)} \quad (9)$$

Figure 19 shows the derived sound speeds at two levels above ground. While sound speed itself may not be too relevant an atmospheric effects quantity, the STO will eventually make available the outputs of detailed models such as range-attenuated sound propagation. Figure 20 shows the output from the ARL Scanning Fast-Field Program (SCAFFIP, Noble 1991) acoustic model in which the wind direction and vertical changes in the wind speed also play major roles. The color contours show preferential propagation directions. (Fig. 20 shows attenuation with range over different compass headings.) One challenge is to find a way to display such range and direction-dependent area contours in a 3-D viewer.

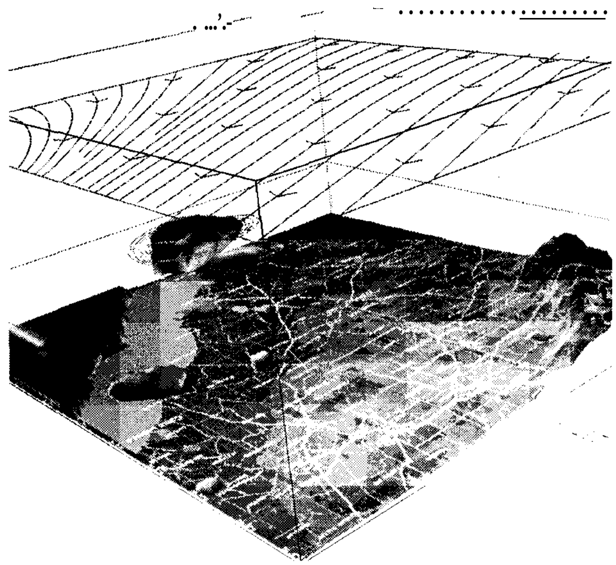

Figure 18. Refractivity and Liquid Water Content

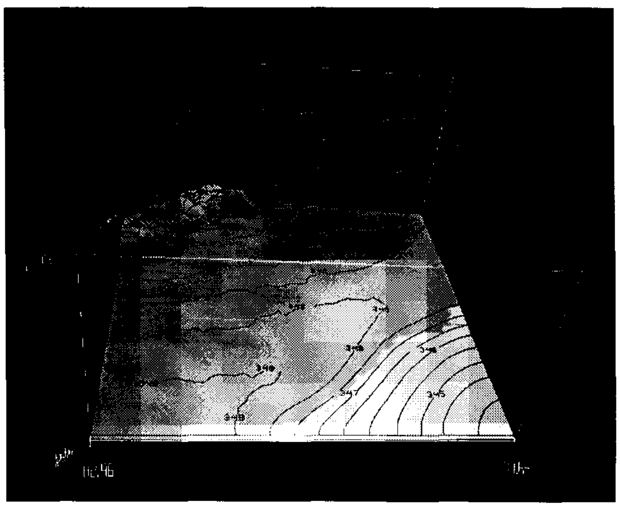

Figure 19. Sound Speed at Two Levels

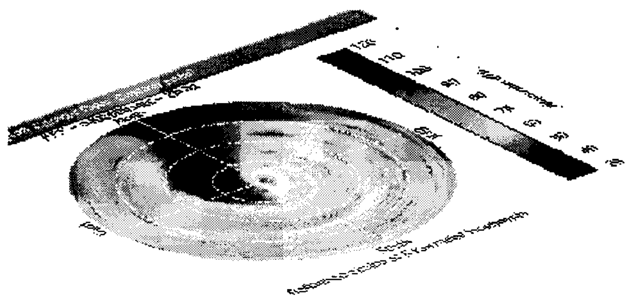

Figure 20. Acoustic Propagation from SCAFFIP

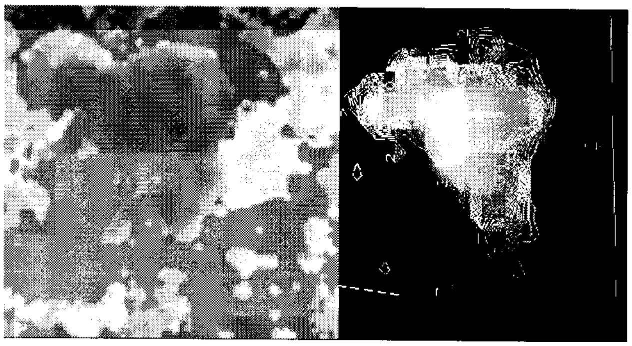

Figure 21. Modeled Clouds Seen from Below

Another example of a future capability is to display natural clouds along with various properties such as concentration, transmission and radiance. Figures 21 and 22 show modeled clouds based on their transmission and radiance (Tofsted, 1996) on the left and top, and Vis5D display of cloud liquid water content (concentration) contours on the right and below. In future such data may also be derived from satellite imagery and forecast liquid water content.

PERFORMANCE CONSIDERATIONS

Vis5D executes extremely well on computers with dedicated graphics hardware. On the SGI, the screen update is approximately 3 to 20 frames/see depending on the amount of displayed data. On the Sun Spare 20 ACHS the corresponding rates using the Mesa graphics library in the main cpu are about 1/10 the SGI rate. (Visualizations are virtually identical on both systems.) However, in prototype tests for IMETS at JWID-96, these are sufficient for interactive data analysis and publication on the IMETS homepage.

CONCLUSIONS

We have detailed here the use of the Vis5D graphics software for the real-time, interactive 3-D visualization of forecast data from the BFM model. Vis5D is being integrated into IMETS in the Spring of 1997 for evaluation. If evaluations go well, then Vis5D is expected to become available on the tactical battlefield for the display and analysis of weather. In future, the data and tactical weather forecast capabilities of IMETS will be made available by ARL to the mission planning, simulation and training communities through an Army Science and Technology Objective. In turn, various weather effects models and simulations will be adapted and evaluated for their use in tactical forecasting of effects and to upgrade current tactical battlefield software for the display of impacts on systems and operations.

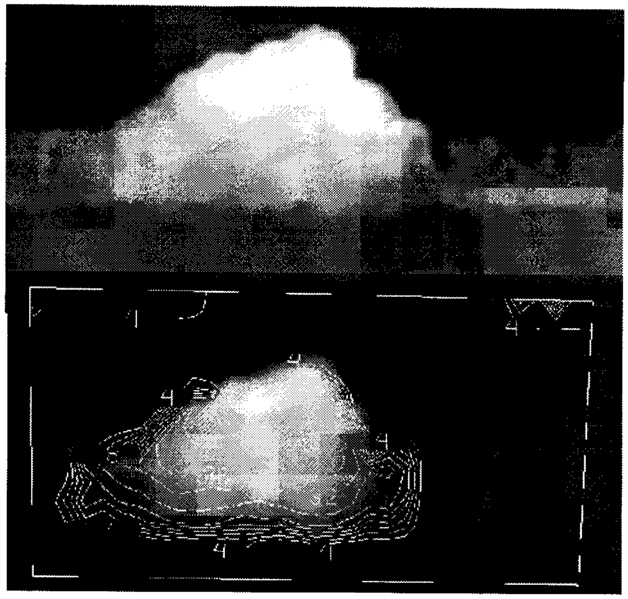

Figure 22. Modeled Clouds from the Side

REFERENCES

Cionco, Ronald and Beyers, J. (1995). High Resolution Wind Field Simulations Run Real-Time During the MADONA Field Study, in Proceedings of 11th Symposium on Boundary Layers and Turbulence, Mar 7, 1995, Charlotte, NC, pp 323-326, by the American Meteorological Society, Boston, MA.

Hibbard, Bill and Paul, Brian, (1996). Overview of Vis5D, Version 4.2, available on-line at http: //www.ssec.wisc .edu/-billvis5d5 htmlml or ftp: iris.ssec.wise.edu, Space Science and Engineering Center, University of Wisconsin - Madison, 1225 West Dayton Street, Madison, WI 53706

Lee, Martin, et. al. (1994). Us. Army Battlescale Forecast Model, in Proceedings of the 1994 Battlefield Atmospherics Conference, 1 Dec 94, Army Research Laboratory, White Sands Missile Range, NM.

Noble, John (1991). Acoustic Propagation in the Atmosphere Using the Scanning Fast Field Program, in Proceedings of the 1991 Battlefield Atmospheric Conference, 3 Dec 1991, Ft. Bliss , TX. Available from ARL, IS&T Directorate, Adelphi, MD.

Tofsted, David and O'Brien, Sean (1996). Application of the WAVES Modeling Suite to the Visualization of Natural Cloud Fields, in proceedings of the 1996 Battlescale Atmospherics Conference, Dec 1996, San Diego, CA (these proceedings).